

WORKSHOP SUMMARY NEW SILICON CELLS

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This report summarizes the workshop on new silicon cells held during SPRAT XII. A smaller than average group attended this workshop reflecting the reduction in research dollars available to this portion of the photovoltaics community. Despite the maturity of the silicon technology, a core of the group maintained an excitement about new developments and potential opportunities. The group addressed both the implications and the applications of recent developments.

LIGHT TRAPPING AND ULTRATHIN SILICON CELLS

Discussion of these two topics is combined because of their potential interaction. Benefits from ultrathin silicon cells include lightweight, high V_{oc} (for $L_n \gg W_B$), and potentially higher end-of-life performance when exposed to radiation. To achieve these benefits, back-surface fields, back-surface reflectors, and light trapping are required. The problems associated with these cells are difficulty in fabrication, handling, and assembly; radiation sensitivity of V_{oc} ; and high costs associated with production and the techniques required to obtain and maintain high cell efficiencies.

Light trapping is a particularly nice concept to couple with ultrathin cells. First-order light trapping (e.g., nonreflective surfaces, antireflective coatings, and reflective back contacts) are already incorporated into cells in a cost-effective manner. Its effectiveness may increase with decreasing cell thickness; but below a certain thickness, the difficulty in its implementation may become prohibitive. To compound the problem, many of the techniques for light trapping and fabricating ultra-thin cells are incompatible. Furthermore, cost-containment techniques generally destroy the very benefits sought in both light trapping and ultra-thin cells. Unless some new techniques are developed, it is not likely that higher-order light trapping (e.g., orthogonal grooving, front and back) will be feasible for high production. Any devices produced using such techniques must also be lightweight, cost effective, and radiation stable to find an adequate customer base. Solar cell vendors will incorporate any option that a customer base will support. However, a major effort is not likely to be made to create such a base unless a clearly superior technology, that is also inexpensive, presents itself.

DIFFERENT USES FOR SILICON CELLS

Two uses for silicon cells were discussed that, while not new, were different applications of a conventional technology. As a medium bandgap material, silicon is appropriate as a bottom cell of a favorable pair (e.g., 1.7:1.1 eV) for either one sun or concentrator application. In this latter application, some of the constraints of normal use are relaxed. Without concern about blue response, the junction can be made deeper to perhaps improve red response, V_{oc} , and fill factor. If a two-terminal monolithic tandem cell is being designed, the tunnel junction necessary to connect the two parts eliminates the need for a highly conductive emitter layer in the silicon. The need to conduct current to grids in the silicon cell may vanish and methods for reducing surface recombination velocity are greatly altered. The use of nonreflective (pyramid or, maybe, V-groove) surfaces could, in addition to improving longwave length response, provide a means of

stress relief and thereby increase the number of useful top cell materials. Two terminal, mechanically stacked tandem cells, using Si as the under-cell, are being evaluated.

As a stable, sturdy, heat-conductive, well-characterized material, silicon has much going for it as a bottom cell. However, the very thing that recommends it, good long-wavelength response, makes it radiation sensitive. Fortunately, some of the techniques for increasing normal silicon cell efficiencies (e.g., light trapping, cell thinning, optimized doping, etc.) work here as well and could actually improve radiation hardness. In a concentrator configuration, heat which limits silicon cell performance, has much less effect if silicon is used as a bottom cell rather than alone. The bandgap narrowing, which lowers V_{oc} , also increases IR response. In this application, the reduction in silicon cell V_{oc} is proportionately less (because of the higher combined cell voltage) and the increase in I_{sc} is proportionately higher (because of the division in cell current between the two cells).

A second "different" use for silicon cells is that of a thermal photovoltaic (TPV) converter in conjunction with a selective emitter (SE). SEs have, in addition to the normal black body radiation spectrum, characteristic emission lines in the shorter wavelength region. Some materials, such as Yb_2O_3 , have emission lines below the silicon absorption edge and, therefore, could convert thermal energy into wavelengths that experience a high conversion efficiency in silicon. A SETPV converter in space has advantages in that thermal isolation between source and converter is simpler than within an atmosphere. However, it is not likely to compete with sunlight, if available, since heat sources still add weight.

Of the two different uses of silicon cells discussed in the workshop, the space application as a bottom cell appears to be more immediately appropriate and commercially important. The use of silicon in a SETPV converter would appear to be more limited in its application (e.g., deep space or low earth orbit where array drag is unacceptable). Future research in this latter case would need to be in the source rather than in the converter area.

NEW SILICON CELL DEVELOPMENTS

Four new silicon cell developments were discussed in the workshop. Two were material oriented, for cost reduction, and two were optimized for high efficiency. The two material-oriented developments were the Spheral™ cell and the Si Film™ cell. Both use lower grade silicon as the starting material and production techniques capable of significant economies when scaled up. The Spheral cell has limitations in that the small silicon balls (typically on the order of 25-mils across) are not high-grade single-crystal silicon, despite dramatic improvement in quality by-process steps; are not lightweight; and have low packaging densities relative to normal solar cell arrays. However, they are flexible and radiation resistant (poor starting material) and the technology has not been optimized.

The Si Film cells are not yet highly efficient, but they have more promise in this area than do the Spheral cells. They are expected to be low-cost, thin, poly-silicon sheet on a flexible substrate that is compatible with very large scale production.

The two high-efficiency Si cell developments, from Stanford University and the University of New South Wales (UNSW), have a lot of features in common and are getting even closer together with time. Both utilize high-diffusion-length silicon, very good surface passivations, reduced contact and emitter areas, and carrier trapping. They are both extremely sensitive to radiation damage (ionizing as well as displacement) and degrade much further than conventional silicon cells. While there are techniques available to reduce damage from ionizing radiation, these cells will have their application in nonradiation solar environments and in nonsolar (e.g., TPV, laser, etc.) areas.

Of the four new developments discussed, the Si Film cells seemed to have the greatest potential for general space use (in lightweight deployable arrays) but would be competing with CIS and a-Si sheet arrays for that slot. The terrestrial applications of this technology could greatly reduce costs and, therefore, increase its viability for space.

A fifth new silicon cell development discussed, the buried defect cell, is burdened with a large question mark. The source of the claim for major improvements in a silicon cell is basically unknown and untested in the West; no cells supporting the claim exist; no single investigator has seen the fabrication and test processes through even a major portion of their cycles; the cell on which the claim is based is very small (~2mm on a side); and the technology is unlike

any applied to solar cells heretofore. However, the claims of very high efficiencies and long wavelength response beyond the silicon bandedge, if verified, could revolutionize silicon solar cell technology.

Briefly the process consists of a high-dose proton implant (180 keV , 10^{16} p/cm^2) with grid lines masked, a flash anneal to form voids beneath the surface, a high temperature anneal (carefully controlled to $\sim 1430^\circ\text{C}$) to regrow the single crystal silicon and to passivate the void surfaces; and an extended boron diffusion and drive-in.

In addition to the uncertainty in measurement technique and results, there are inconsistencies in the fabrication process (e.g. implant energies and defect layer depth do not agree). To compound the problem of general application to space, the material costs are greatly increased if large area implant and long-term anneal and diffusion steps are required. Nevertheless, if even half the claims are valid, cost-effective means of achieving them might well be found.

RADIATION TOLERANT HIGH EFFICIENCY CELLS

Typically, as the efficiency of a solar cell is improved, its susceptibility to radiation damage is also increased. Sometimes the changes offer no improvement in end-of-life (EOL) performance so that beginning of life (BOL) improvements mean higher degradation rates. Sometimes the changes actually decrease the EOL performance. Occasionally a cell improvement for one purpose reduces performance in another area, but gives net gains in EOL performance. The high-efficiency silicon cells discussed in the workshop are not likely to be radiation tolerant. The possible exception is a variant of the buried-defect-layer solar cell. The UNSW and Stanford cells could be made less radiation sensitive than they are presently; but they will always drop below the normal cell output at some fluence (between 10^{14} and $5 \times 10^{14} \text{ 1 MeV e-/cm}^2$). The buried defect layer cell may display higher performance despite a lower performance starting material. If this is the case, onset of degradation will be at higher fluences and EOL performance will be higher than that of normal cells, if passivation of the buried surfaces are not critical or if they can be radiation hardened.

CONCLUSIONS

As presently manufactured, space-grade silicon solar cells are unlikely to be changed drastically unless the buried defect layer cell, or derivative ideas, can be verified and implemented in a reasonable manner. The low-cost, low-weight possibilities presented by the Si Film cells may make them a viable option in the future.